Q 67: Optomechanics III

Time: Friday 11:00–13:00 Location: F442

Q 67.1 Fri 11:00 F442

Direct laser-written optomechanical membranes in fiber Fabry-Perot cavities — •Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments in micro- and nanophotonic systems have demonstrated record optomechanical coupling strenghts, but require elaborate techniques for interfacing. Their scaling towards larger systems including many mechanical and optical resonators is limited. Here, we demonstrate a directly fiber-coupled tunable and highly flexibile platform for cavity optomechanics based on 3D laser written polymer structures directly integrated into fiber Fabry-Perot cavities. Our experiments show vacuum coupling strengths of $\gtrsim 30\,\mathrm{kHz}$ at mechanical mode frequencies of $\gtrsim 3\,\mathrm{MHz}$. This allows us to optomechanically tune the mechanical resonance frequency by tens of kHz exceeding the mechanical linewidth at cryogenic temperatures of $\sim 6\,\mathrm{kHz}$ at 4 K. The ease of interfacing the system through the direct fiber coupling, its scaling capabilities to larger systems with coupled resonators, and the possible integration of electrodes makes it a promising platform for upcoming challenges in cavity optomechanics. Fiber-tip integrated accelerometers, directly fiber coupled systems for μ-wave to optics conversion or large systems of coupled mechanical resonators are in reach.

Q 67.2 Fri 11:15 F442

Hollow core photonic crystal fibers as sources for levitated nanoparticles in future quantum experiments — •Stefan Lindner, Yaakov Fein, Paul Juschitz, Jakob Rieser, Markus Aspelmeyer, and Nikolai Kiesel — University of Vienna, Faculty of Physics

Over the last decade several proposals using optically levitated nanoparticles as a platform to create macroscopic quantum states have been put forth. Yet as of today environmental decoherence still poses a substantial roadblock hindering the access to such experiments. Especially the interaction with background gas molecules has to be overcome by reducing the pressure these experiments are conducted in. The attainable vacuum for levitation experiments is directly related to the type of particle loading scheme in place. Here we present a novel method for loading nanoparticles via hollow core photonic crystal fibers, that allows direct loading of into pressures in the ultra high vacuum (UHV) regime.

By guiding two counter-propagating lasers of equal wavelength through a hollow core fiber one creates an “optical conveyor belt” that connects an UHV pressure main vacuum chamber to an ambient or low vacuum “loading” chamber. By detuning one of the two lasers with respect to the other, nanoparticles can be transported from the loading chamber, through the fiber, directly into the trap in the main vacuum chamber. This handover of particles has been demonstrated down to pressures of 10^{-8} mbar and is currently extended, targeting below 10^{-10} mbar, where gas collisions occur at sub-kHz timescales.

Q 67.3 Fri 11:30 F442

Tunable light-induced dipole-dipole interaction between optically levitated nanoparticles — •Jakob Rieser[1], Mario A. Ciampini[1], Henning Rudolph[2], Nikolai Kiesel[1], Klaus Hornberger[2], Benjamin A. Stickler[2], and Uroš Delić[1] — [1]Faculty of Physics, University of Vienna, Vienna, AUT — [2]Faculty of Physics, University of Duisburg-Essen, Duisburg, DEU

By coupling mechanical systems one can observe interesting collective effects, such as topological phonon transport or in the quantum case the possibility of entanglement. Current optomechanical experiments utilize an optical cavity mode to mediate interactions, which limits the tunability of the system. Here we are interested in directly coupling parties using scattered light in a finely controlled manner.

It has been known that optically levitated microparticles can interact through light – optically bind – and form self-organized patterns that resemble crystals. In my talk, I will present coherent, direct interaction between two dielectric nanoparticles levitated in a trap array. In contrast to previous optical binding studies, the interparticle coupling is inherently non-reciprocal. I will show how tuning the relative optical phase, laser powers, and the particle distance gives us full control of the optical interactions. Finally, I will demonstrate how we can suppress the optical coupling using the light polarization, in which case we can observe electrostatic interactions.

Q 67.4 Fri 11:45 F442

Co-trapping an atomic ion and a silica nanoparticle in a Paul trap — •Dmitry S. Bykov, Lorenzo Dania, Florian Goschin, and Tracy E. Northup — Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

In this work, we experimentally demonstrate the simultaneous trapping of two objects whose charge-to-mass ratio differs by six orders of magnitude in the same Paul trap. The first object is a calcium ion with a single elementary charge and a mass of 40 Da. The second object is a silica nanoparticle with 1000 elementary charges and a mass of 10^{10} Da. To achieve simultaneous trapping, we drive the trap electrodes with two radio-frequency tones: one to trap the nanoparticle and the other to trap the atomic ion. Such a dual-frequency drive allows us to circumvent the charge-to-mass selectivity of a Paul trap. This demonstration paves the way for building a hybrid ion-nanoparticle system under ultra-high vacuum. Such a system is a promising platform for advancing quantum control of particle motion and testing quantum mechanics at unprecedented levels.

Q 67.5 Fri 12:00 F442

Optomechanics with a torsional mode of an optical nanofiber — •Jihao Jia, Sebastian Pucher, Arno Rauschenbeutel, Philipp Schneeweiss, Felix Tebbenjohanns, and Jürgen Volz — Humboldt-Universität zu Berlin, Germany

Tapered optical fibers (TOFs) with a sub-wavelength-diameter waist, so-called optical nanofibers, have proven to be extremely versatile tools with applications ranging from telecommunication devices and sensors to trapping and optically interfacing laser-cooled atoms. Surprisingly, in the realm of optomechanics, the mechanical motion of the nanofiber waist of such TOFs is so far largely unexplored. Here we show experimentally that the torsional motion of the nanofiber waist of a TOF can be extremely well decoupled from the environment, reaching quality factors of up to 10 million. By analyzing the polarization fluctuations of a probe light field transmitted through the TOF, we measure the nanofiber's torsional motion in real time. Feeding back this signal to the nanofiber, we cool its fundamental torsional mode by several orders of magnitude to sub-Kelvin temperatures. Based on our observations, we discuss the prospects of ground-state cooling. Our results show that optical nanofibers represent a competitive optomechanical platform, which may enable new hybrid quantum systems, e.g., by coupling the torsional motion to cold atoms that are trapped in the evanescent field surrounding the nanofiber.

Q 67.6 Fri 12:15 F442

Strong Coulomb interaction between highly charged optically trapped sub-micron particles in vacuum — •Ayub Khodaee[1], Anton Zasedatelev[1], and Markus Aspelmeyer[1,2] — [1]Faculty of Physics, Boltzmanngasse 5, 1090 Wien, Vienna, Austria — [2]IQOQI - Vienna, Boltzmanngasse 3, 1090 Wien, Vienna, Austria

Optically levitated nano- and micro-particles, in which the motion of a mechanical degree of freedom is controlled via light-induced forces, comprise a new class of ultimately isolated macroscopic mechanical oscillators with high-quality factors exceeding 108 [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. One of the central goals of levitated optomechanics nowadays is to prepare a particle wave packet in a sufficiently pure quantum state and generate entanglement between macroscopic mechanical oscillators [Gonzalez-Ballestero, C., et al., Science 374.6564 (2021): eabg3027]. Strong electrostatic interaction between highly charged levitated particles is one the most promising strategies to generate stationary entangled states. The preparation of a pair of highly charged optically levitated particles in the ultra-high vacuum (UHV) is an experimental challenge on the way to implement ground state cooling and quantum entanglement between optically trapped particles. Here we address this problem and present our experimental approach to load, charge, and control sub-micron particles in tunable optical traps in UHV.

Q 67.7 Fri 12:30 F442

Numerical analysis of a novel optical trap design based on optomechanical backactions — •Jose Manuel Monterrosas Romero[1,2], Ester Koistinen[1], Seyed Khalil Alavi[1,2], and Sungkun Hong[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Universität Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, 70569 Stuttgart, Germany

Optical traps have proven to be an invaluable tool for many scientific applications. However, due to the nature of the traps, their spatial shapes are diffraction limited, and a trapped object often suffers from severe absorption heating, especially in a high vacuum. To mitigate these issues, we propose a new type of optical trap based on the use of dynamic optomechanical backactions between optical nanocavities and a dielectric particle. Our trap consists of two photonic crystal nanobeam cavities (PCNC) closely placed in parallel. Numerical simulations confirm that an extremely sharp potential can be created in the middle between the two PCNCs, which can trap a dielectric nanoparticle stably at room temperature. Furthermore, we find that the dynamic optomechanical forces allow for trapping the particle with significantly suppressed optical heating, therefore reducing heat-induced trap instability. We also present the possibility of creating more complex trapping potentials by adding a second beam with different frequencies for each cavity. All of these unique properties make our system a promising trapping platform for levitated optomechanics.

Q 67.8 Fri 12:45 F442

On a way to quantum entanglement via Coulomb interaction between optically trapped macroscopic particles — •Anton Zasedatelev[1], Ayub Khodaee[1], Klemens Winkler[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna — [2]The Institute for Quantum Optics and Quantum Information

The quantum superposition principle and entanglement are one of the most striking features of the microscopic world and the key resource behind emerging quantum technologies, including quantum telecommunication, computing, metrology etc. The quantum entanglement of macroscopic mechanical oscillators is a unique resource to examine fundamental principles of quantum mechanics at the interface with classical physics. Electromagnetically induced quantum entanglement of macroscopic objects is essential for understanding the role of electromagnetic radiation quantization and vacuum fluctuations in ensuring consistency of the macroscopic systems to the basic principles of quantum mechanics, e.g. causality and complementarity. Here we discuss experimental challenges towards generation of quantum entanglement between center-of-mass motions of two highly charged sub-micrometer dielectric particles optically levitated in an ultra-high vacuum. This work is in progress, and takes the following steps: (i) optical trapping of two closely located and highly charged particles (ii) ground state cooling of their mechanical normal modes, (iii) generation and measurement of entanglement through long-range Coulomb interaction.